Deployment of Low-Cost Sensors for the Uintah Basin

Final Report

Prepared for:
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320 N. Aggie Boulevard
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Under Purchase Orders P0433805-E and P0463046

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Abbreviations/Acronym List

ASOS	Automated Surface Observing System
CBM	Coalbed methane
CEAS	Cavity Enhanced Absorption Spectroscopy
CH4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
ERG	Eastern Research Group, Inc.
HC	Hydrocarbons
IR	Infrared
MEMS	Micro-electro mechanical system
MOX	Metal Oxide
MSCF	Thousand standard cubic feet
$\mu g/m^3$	Micrograms per cubic meter
ND	Non-detects
NDIR	Non-dispersive Infrared
NO_2	Nitrogen dioxide,
O_3	Ozone
PID	Photo-Ionization Detector
$PM_{1.0}$	Particulate matter less than or equal to 1.0 micron in aerodynamic diameter
$PM_{2.5}$	Particulate matter less than or equal to 2.5 microns in aerodynamic diameter
PM_{10}	Particulate matter less than or equal to 10 microns in aerodynamic diameter
ppb	Parts per billion
ppm	Parts per million
UDAQ	Utah Division of Air Quality
VOC	Volatile organic compounds

1.0 INTRODUCTION AND OVERVIEW

This report documents the deployment of low-cost sensors for the Uintah Basin, including lessons learned and data analysis of the measurements during a short-term field study.

The State of Utah is home to complex topography, meteorology, mineral resources, large emission sources, and land use terrains that have created challenges for air quality management. The Utah State Legislature sets aside annually research funding for the "Science for Solutions" program to improve air quality. Topic areas are prioritized each year and are focused on Utah-specific air quality issues such as wintertime ozone, particulate matter less than or equal to 2.5 microns in aerodynamic diameter ($PM_{2.5}$), and emerging technologies.[1]

1.1 Project Motivation

Recent studies of wintertime ozone pollution in the Uintah Basin have indicated that underestimation of organic compound emissions and inadequate organic compound speciation profiles in existing oil and gas emission inventories are the main reasons leading to underestimation of ozone concentrations simulated by photochemical models. The Uintah Basin contains nearly 11,000 active oil, gas, and coalbed methane (CBM) wells. In 2020, the basin produced over 26.0 million barrels (BBL) of liquids (oil/condensate), 224.0 million thousand standard cubic feet (MSCF) of gas (natural gas and associated gas), and 22.7 million MSCF of CBM gas.[2]

Under "Goals and Priorities" for the 2020 Fiscal Year grant, Low-Cost Sensors were identified as an area of research needed to supplement ground-based air monitoring stations. New air monitoring technologies with increased spatial and temporal resolution have emerged in the last few years. The Utah Division of Air Quality (UDAQ) is interested in evaluating the sensors' limitations and performance under environmental conditions, especially in oil and gas rich areas such as in the Uintah Basin.

Under Purchase Orders P0433805-E and P0463046 to the Bingham Research Center at Utah State University in Vernal, UT, Eastern Research Group, Inc. (ERG) researched, tested, and deployed low-cost sensors for total volatile organic compounds (VOCs) and methane (CH_4) to support this research goal. ERG developed several programmatic questions to guide this assessment:

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[1] Completed and on-going studies are presented at: https://deq.utah.gov/category/air-quality/aq-applied-research-studies.

[2] Production statistics are presented at: https://oilgas.ogm.utah.gov/oilgasweb/statistics/statistics-main.xhtml.

- What are the available commercial low-cost total VOC and CH_4 sensors?
- What are the strengths and limitations of available commercial low-cost total VOC and CH_4 sensors?
- How do low-cost total VOC and CH_4 sensors perform under laboratory conditions?
- How do low-cost total VOC and CH_4 sensors perform under field conditions?
- Are the measurements from low-cost total VOC and CH_4 sensors pointing to anthropogenic emission sources?

1.2 Project Timeline

Table 1-1 presents the timeline for the project.

Table 1-1. Tasks and Timeline

Task	Timeline
Task 1 – Research low-cost VOC sensors	August 2019 – November 2019
Task 2 – Identify and purchase low-cost VOC sensors	November 2019 – December 2019
Task 3 – Testing low-cost VOC sensors	January 2020
Task 4 – Deploying low-cost VOC sensors	February 2020 – April 2020
Task 5 – Data Analysis	May 2020 – March 2021
Task 6 – Final Report	April 2021 – June 2021

1.3 Organization of the Report

This report is divided into six sections and 1 appendix.

- Section 1 introduces the purpose of this report.
- Section 2 presents an overview of low-cost VOC sensors researched and chronicles the identification and purchase of low-cost VOC sensors.
- Section 3 discusses the testing of low-cost VOC sensors under laboratory conditions and deployment in the field.
- Section 4 summarizes the measurements collected.
- Section 5 presents observations from the study.
- Section 6 presents the references from the literature survey.
- Appendix A presents the sensor measurements collected and hourly meteorological data from the nearest Automated Surface Observing System (ASOS) station.

2.0 REVIEW OF AVAILABLE LOW-COST VOC SENSORS

This section chronicles ERG's efforts to identify available sensors for methane and total VOCs.

Low-cost sensors for criteria pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), O_3, and $PM_{2.5}$ sensors are commercially available and are used for air quality study applications nationwide.[3,4,5] These non-regulatory sensors are used primarily to supplement traditional monitoring and are often placed in locations to assess community exposure or source influence.

While sensors are available for VOC and CH_4 for leak detection at industrial facilities, the concentration range effectiveness is not typically suitable for ambient air conditions. As such, low-cost sensors for VOC and CH_4 for ambient air conditions are not as widely available compared to the above criteria pollutant sensors.

2.1 Low-Cost Sensors Reviewed

At project initiation, ERG performed a literature search, surveyed the sensor market via the internet for commercially available and updated sensor products, interviewed manufacturers, and reviewed information from South Coast's Air Quality Sensor Performance Evaluation Center (AQ-SPEC) and EPA guidance documents to identify and rank VOC and methane sensors for potential consideration. Initially, the focus of the project was to deploy multiple sensors at multiple locations in the Uintah Basin.

The literature search using Proquest Agricultural and Environmental database services yielded nearly 50 peer-reviewed journal articles[6] for the years 2012 to 2019 using search terms which provided useful information on the sensor-types and products used for methane and VOC detection. Table 2-1 presents the VOC and CH_4 sensors chosen from the literature review and were commercially that were reviewed and available, as of September 2019. Data presented include: sensor manufacturer/model; pollutant(s); sensor type; detection range, and approximate cost. Specific considerations for sensor selection include:

- Low-cost (< $500)

[3] EPA's Air Sensors Toolbox presents sponsored studies: https://www.epa.gov/air-sensor-toolbox/past-research-projects-using-air-sensor-technology

[4] City of Denver's Love My Air: https://www.denvergov.org/Government/Departments/Public-Health-Environment/Environmental-Quality/Air-Quality/Love-My-Air

[5] Completed and on-going studies are presented at: https://deq.utah.gov/category/air-quality/aq-applied-research-studies.

[6] See Section 6 for a list of references from the literature search.

- Low-power (<12 volts)
- Low detection levels suitable for ambient conditions
- Continuous measurements (a minute or less)
- Commercially-available
- Economically feasible

Table 2-1. Summary of Low-Cost Sensor Models Reviewed for this Study

Sensor Manufacturer (Model)	Pollutant(s)[a]	Sensor Type[b]	Detection Range	Cost ($)
Aeris (MIRA PICO LDS)	CH_4	IR	0.1-10,000 ppm	$350
Aeroqual (AQS 65)	Total VOCs	PID	0.1-20 ppm	$1,500
Aeroqual (Series 500)	CH_4	MOX	0-100 ppm	$1,250
Alphasense (AH2)	Total VOCs	PID	1-50 ppbv	$700
Alphasense LTD (IRM-AT)	CH_4	MOX	0-2.5%	$1.00
Alphasense LTD (MMO VOC)	Total VOCs	MOX	1-100 ppm	Need quote
Applied Sensor AMS (iAQ-Core C)	Total VOCs	MOX	125-600 ppbv	$20
Baseline-Mocon (Series 9000 Total HC)	CH_4	MOX	1-2000 ppm	Need quote
Baseline-Mocon (VOC-Traq)	Total VOCs	PID	0.1-2,000 ppm	$215
City Technology (IR-CelCH4)	CH_4	IR	0-5%	$585
City Technology (Micropel 75M)	CH_4	IR	0-3%	$157
CrowCon (Laser Methane Mini)	CH_4	NDIR	0-100%	$1,700
Dynament (MSH2ia-LS/HC/CO_2)	CH_4, CO_2	IR	0.01-5%	$100
Dynament (MSH2-LP/HC)	CH_4, CO_2	IR	0.01-5%	$100
Edinburgh Sensors (Gascard CH_4)	CH_4	NDIR	300-10,000 ppm	$2,000
Figaro Engineering (TGS-2600)	CH_4	MOX	7-100 ppm	$16
Figaro Engineering (TGS-2611)	CH_4	MOX	500-10,000 ppm	$50
Figaro Engineering (TGS-2612)	CH_4	MOX	500-10,000 ppm	$50
Figaro Engineering (TGS-6812)	CH_4	MOX	0-14,000 ppm	$50
Figaro Engineering (TGS-8100)	CH_4	MOX	10-100 ppm	$20
FIS (SB-11A-00)	CH_4	MOX	300-10,000 ppm	No response
FIS (SB-12A)	CH_4	MOX	500-10,000 ppm	No response
Foobot (FBT0002100)	Total VOCs	MOX	125-1,000 ppb	$200
Futurelec (MQ-4)	CH_4	MOX	300-10,000 ppm	$4.00
GDS (Gasmax)	CH_4	NDIR	1-100%	$3,200
GDS Corp (GDS-48)	Total VOCs, CH_4, CO_2	PID	0-300 ppm	$1,000
GDS Corp (GDS-IR)	CH_4	NDIR	0.1-100%	$1,000
GDS Corp (GDS-IR, Gasmax)	CH_4, HC	IR	0.1-100%	$3,000
Graywolf (Directsen Sen-B TVOC)	Total VOCs	PID	0.1-10,000 ppm	$1,000
Hanwei Electronics (MQ4)	CH_4	MOX	300-10,000 ppm	No response
Hubei Cubic-Ruiyi Instrument Co. (Portable Gas 3100P)	CH_4	NDIR	0-10%	No response

Table 2-1. Summary of Low-Cost Sensor Models Reviewed for this Study

Sensor Manufacturer (Model)	Pollutant(s)[a]	Sensor Type[b]	Detection Range	Cost ($)
IDT (SGA711)	CH_4	MOX	10-10,000 ppm	$30
IDT (ZMOD4410)	Total VOCs, CO_2	MOX	0.1-100%	$150
IBM (APRA)	CH_4	laser	5-25 ppb	$300
Ion Science (Falco Fixed VOC Detector)	Total VOCs	PID	0.01-500 ppm	$1,000
Ion Science (MiniPID2)	Total VOCs	PID	0.005-100 ppm	$1,400
Ion Science (Tiger Handheld VOC Detector)	Total VOCs	PID	0.1-100%	$4,212
Ion Science (TVOC Fixed Detector)	Total VOCs	PID	0.1-100%	$3,000
Ion Science (Typhoon)	Total VOCs	PID	0-1,000 ppm	No response
KWJ Engineering (MEMS Nanosensor)	CH_4	MEMS	0-5%	No response
LI-COR (LI-7810)	CH_4	CEAS	0-100 ppm	$10,000
LOSANT (Canary)	CH_4	NDIR	0-5%	$200
LOSANT (Canary)	Total VOCs	PID		$200
Lunar Outpost (Canary-S)	Total VOCs, CH_4	PID	0.001-40 ppm	$2,755
Maxion Technologies (APRA)	CH_4	IR	5-25 ppb	$10,000
Nemoto (NCP-180S-7S)	CH_4	Pellistor	0-100%	$30
Nova (470 Series)	CH_4	NDIR	0.1-100%	No response
Quanta3	CH_4	IR	5-25 ppb	$3,000
RAE (UltraRAE 3000)	Total VOCs	PID	0.10-100%	$5,000
Renesas Electronic Corp.	CH_4	MOX	10-10,000 ppm	$362
Safe Core Radius (Radius BZ1)	CH_4	MOX	0.10-100%	$4,000
Sensortech (MP-7217)	CH_4	Pellistor	0.10-100%	$50
Sensortech/GSX (INIR)	CH_4	NDIR	4-10%	$233
Sensortech/GSX (IR12 Series)	CH_4	NDIR	0-100%	$172
Sensortech/GSX (IR15TT-R)	HC, CO_2	NDIR	0.1-100%	$260
Sensortech/GSX (NGM)	CH_4	Pellistor	4-100%	$32
Sensortech/GSX (VQ21TB)	CH_4	Pellistor	0-3%	$50
Siemens (Ultramet 23 Analyzer)	CH_4	NDIR	1-100%	$1,500
UniTec (Sens-It)	CH_4,	MOX	1-1,500 ppm	$2,200
UniTec (Sens-It)	Total VOCs	PID	0-15 ppm	No response
UST Umwelt (Sensortechnik)	CH_4, CO_2	MOX	10-10,000 ppm	No response
Winsen (GM-402B)	CH_4	Pellistor	1-1,000 ppm	$30
Winsen (MP-4)	CH_4	Pellistor	300-10,000 ppm	$16
Xi'an Dingyan Technology Co. (DY-Gas Analyzer)	CH_4	NDIR	1-100%	$5,000

[a] CO_2 = carbon dioxide; HC = hydrocarbons

[b] CEAS = Cavity Enhanced Absorption Spectroscopy; IR = Infrared; MEMS = Micro-electro mechanical system; MOX = Metal Oxide; NDIR = Non-dispersive Infrared; Pellistor = gas system; PID = Photo-Ionization Detector;

2.2 Sensor(s) Selection

ERG developed an initial matrix of sensors for CH_4 and Total VOCs based on various parameters and attempted to contact manufacturers which met the selection criteria. Several lessons were gleaned from this exercise:

- While many of the websites did not list prices for the sensors, that information was available only after contacting the manufacturer.
- Sensor prices typically only cover the sensor. Additional costs for housing, communication, data analytics, shipping, and other features tended to increase the price. In some cases, pricing information was not available.
- Some of the identified sensors were not commercially available and would often take weeks to months before delivery.
- Many of the sensor concentration ranges were not low enough for ambient conditions.
- Data ownership is not always apparent.

The technologies for low-cost methane and VOC sensors are still lagging behind other pollutant sensors. As such, the current array of these pollutants was limited. We have identified two sensors, both of which were over the proposed budget per sensor. As such, ERG requested and was approved to reduce the number of sensors for purchase, testing, and deployment. Two sensors were purchased for testing and deployment.

2.2.1 Lunar Outpost Canary-S

In November 2019, ERG ordered a Canary-S Special Order combination methane and total VOC sensor. The timeframe from order to delivery was approximately 2 weeks. The Canary-S sensor box has options for inclusion of multiple parameters. ERG chose the following parameters for the sensor box:

- Methane
- Total Volatile Organic Compounds
- PM_1, $PM_{2.5}$, and PM_{10}
- Outdoor pressure
- Internal temperature and relative humidity

Figure 2-1 presents the sensor box and companion solar power unit. The total sensor box, with monthly data plan, cost $2,855.

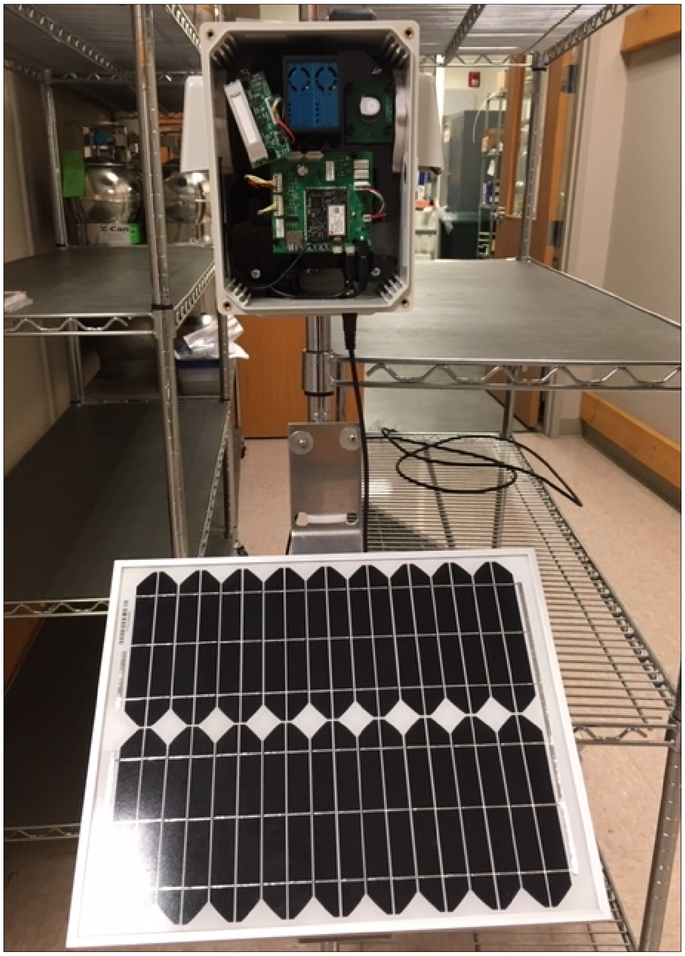

Figure 2-1. Lunar Outpost Sensor

2.2.2 Dynament

In December 2019, ERG ordered a Dynament combination methane/speciated hydrocarbon sensor. The timeframe from order to delivery was approximately 1 week. The Dynament sensor box has options for inclusion of multiple parameters. ERG chose the following parameters for the sensor box:

- Methane
- Total Hydrocarbons
- Outdoor temperature
- Detector, reference, and absorbance signals

Figure 2-2 presents the sensor box. The total sensor box, with housing and data packaging, cost $585.

Figure 2-2. Dynament Sensor Box

3.0 TESTING OF SENSORS AND DEPLOYMENT

This section describes the laboratory tests performed by ERG to test the Lunar Outpost Canary-S sensor and Dynament sensor units for deployment.

As part of this study, ERG performed field tests for each sensor box at its Morrisville, NC laboratory. Two types of tests were conducted for the Lunar Outpost Canary-S sensor unit:

- "Bump" test where a known concentration is released near the sensor to test sensor accuracy and responsiveness.
- "Source" test where the sensor is placed near an idling truck for 20 minutes.

For the Dynament sensor unit, only a "bump" test was performed due to time constraints.

3.1 Lunar Outpost Canary-S Sensor Unit

In early December, ERG conducted a bump test and a source test to evaluate the responsiveness to direct anthropogenic sources. The bump test consisted of exposing the sensor to a canister of 500 ppb concentration of isobutylene for three 1-minute bursts of 11:39am, 11:44, and 11:49. Figure 3-1 presents the results of the total VOC concentrations.

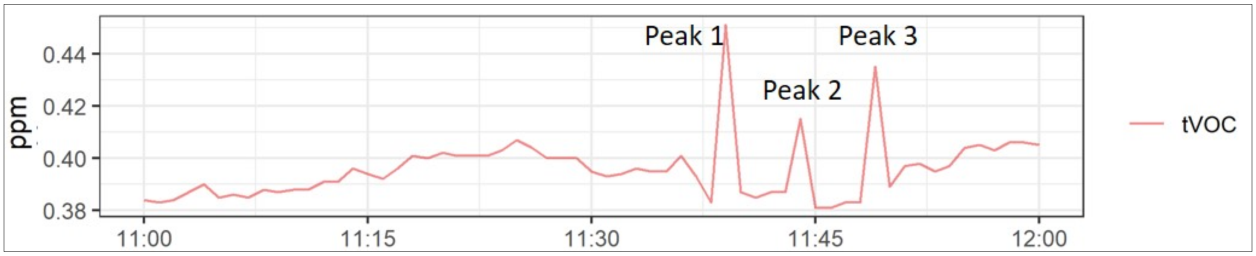

Figure 3-1. Total VOC Concentrations from Bump Test

As presented in Figure 3-1, the results of the bump test indicate good responsiveness of the total VOC sensor, in terms of peak identifications related to exposure of the bump tests. In terms of magnitude, the first peak was roughly 460 ppb, which is close to the 500 ppb isobutylene concentration. Peak #3 measured at 430 ppbv, while Peak #2 measured at 415 ppbv.

Figure 3-2 presents the results of the methane concentrations.

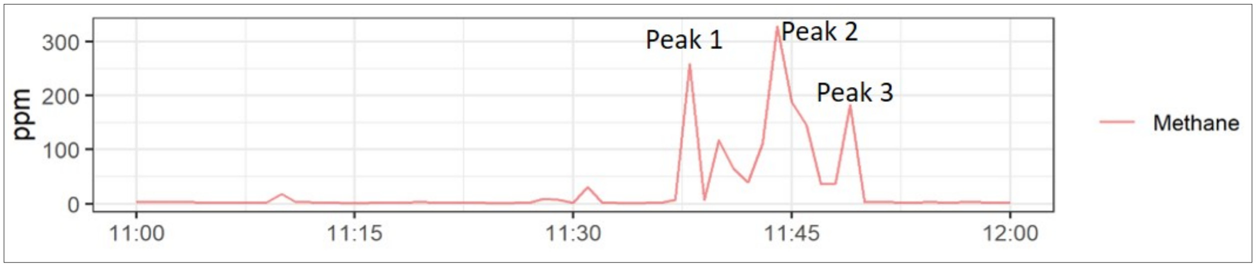

Figure 3-2. Methane Concentrations from Bump Test

As presented in Figure 3-2, the results of the bump test indicate good responsiveness of the methane sensor, in terms of peak identifications related to exposure of the bump tests.

For the source test, ERG ran a Ford F150 in idle for 20 minutes. Figure 3-3 presents the results of the total VOC concentrations.

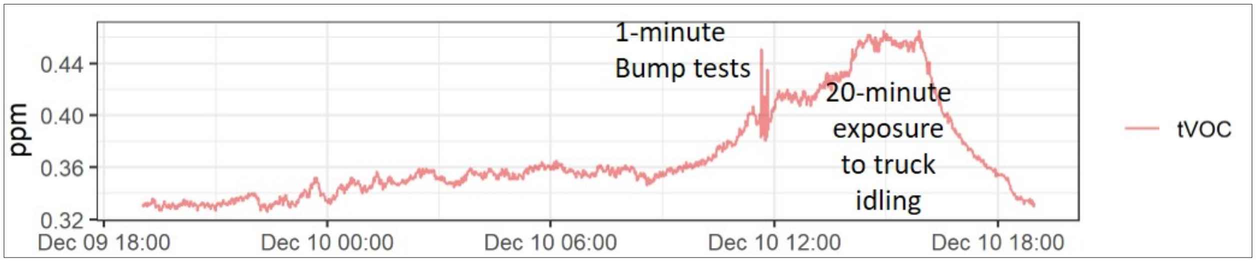

Figure 3-3. Total VOC Concentrations from Source Test

As presented in Figure 3, the results of the source test indicate good responsiveness of the total VOC sensor, in terms of peak identifications related to exposure of the truck idling. In terms of magnitude, the peaks were consistent for the entire 20 minutes, roughly at 480 ppb. When the vehicle shut down, the total VOC concentrations began to decrease.

Figure 3-4 presents the results of the methane concentrations.

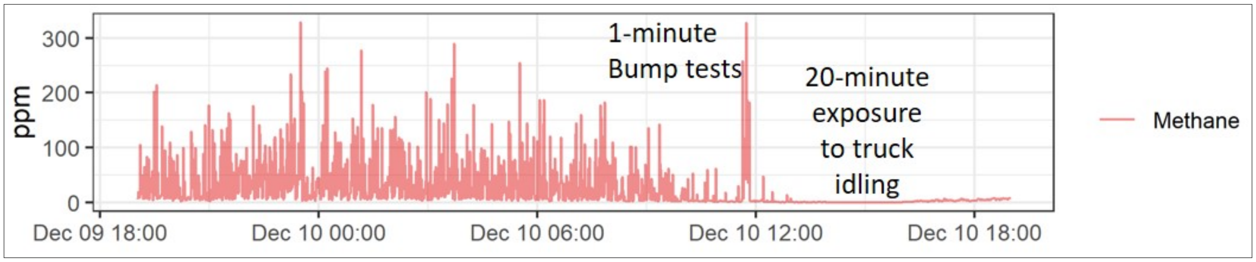

Figure 3-4. Methane Concentrations from Source Test

As presented in Figure 3-4, the results of the source test indicate no responsiveness of the methane sensor, as no peaks were observed. This is somewhat surprising and was worthy of additional investigations. In summary, the total VOC sensor showed good responsiveness to the bump test and the source test. Additionally, the methane sensor showed good responsiveness to the bump test, but not the source test.

ERG also compared the Lunar Outpost data concurrently with a Sensit Sensor that ERG is testing for another project. The Sensit Sensor is roughly priced at $8,000 per unit. Figure 3-5 compares the total VOC concentrations between the two sensors.

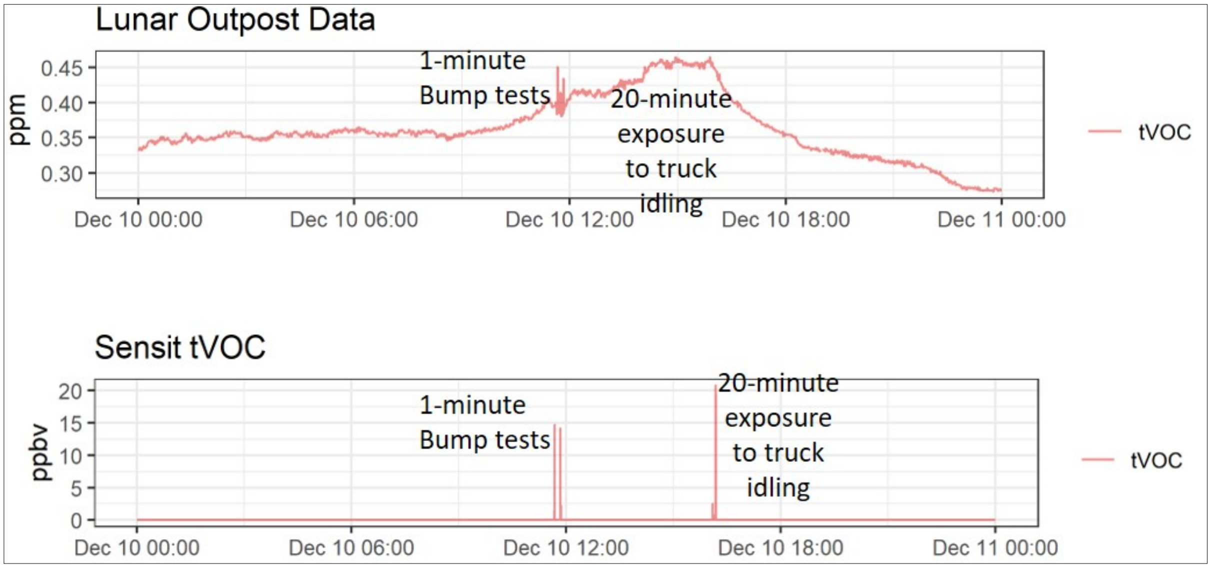

Figure 3-5. Comparison of Total VOCs from the Lunar Outpost and the Sensit Sensor

As presented in Figure 3-5, the results of the identification and magnitude of peaks are in good agreement. However, the baseline values for the Lunar Outpost sensor are much higher than the Sensit sensor, roughly 0.35 vs. close to 0. This is due to the method detection limit of the Sensit sensor being lower than the Lunar Outpost sensor.

3.2 Dynament Combination Methane/Hydrocarbon Sensor Unit

Testing of the Dynament Sensor Unit was delayed until January 2020, as additional parts were needed from the manufacturer when the original sensor arrived in December 2019.

In late January, ERG conducted a bump test to evaluate the methane responsiveness to low and high known concentrations of methane (1%, 2.5%, and 100%). The bump test consisted of five-minute bursts at 10.39am, 10:44am, and 10:50am. Figure 3-6 presents the results of the methane concentrations for the 1% and 2.5% methane bump tests, respectively.

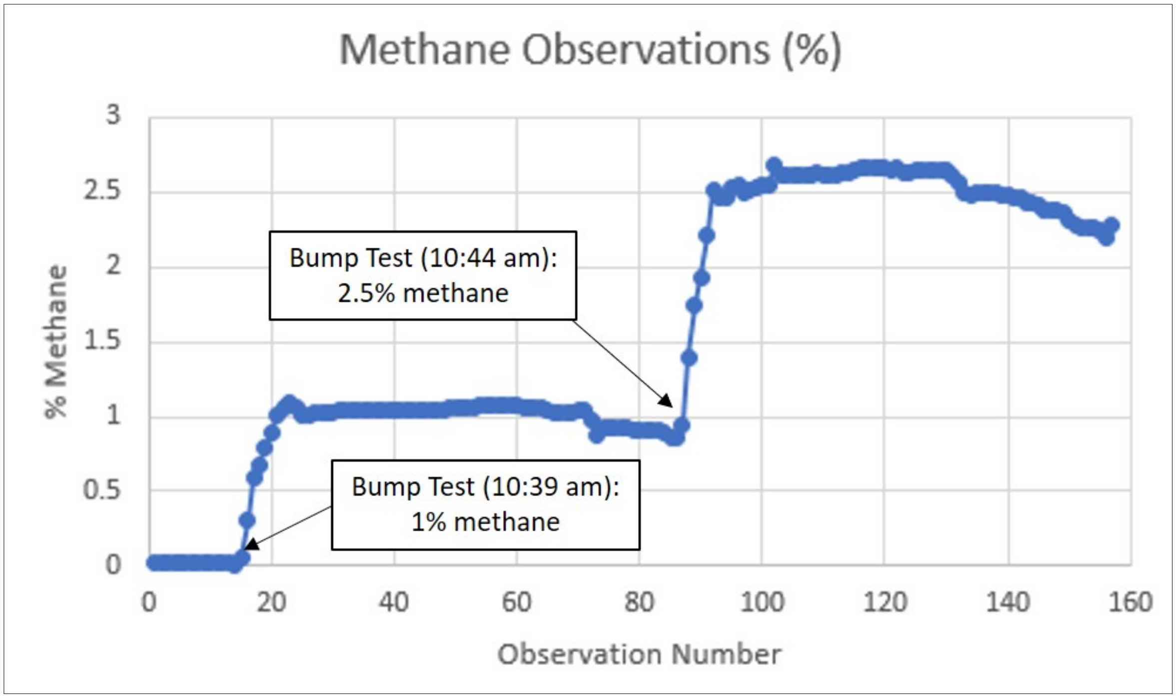

Figure 3-6. Methane Concentrations from the 1% and 2.5% Methane Bump Tests

As presented in Figure 3-6, the results of the bump test indicate good responsiveness of the total methane sensor, in terms of peak identifications related to exposure of the low-level methane bump tests. In terms of magnitude, the peaks were detected shortly after the known concentrations were injected.

Figure 3-7 presents the results of the methane concentrations for the 100% methane bump test.

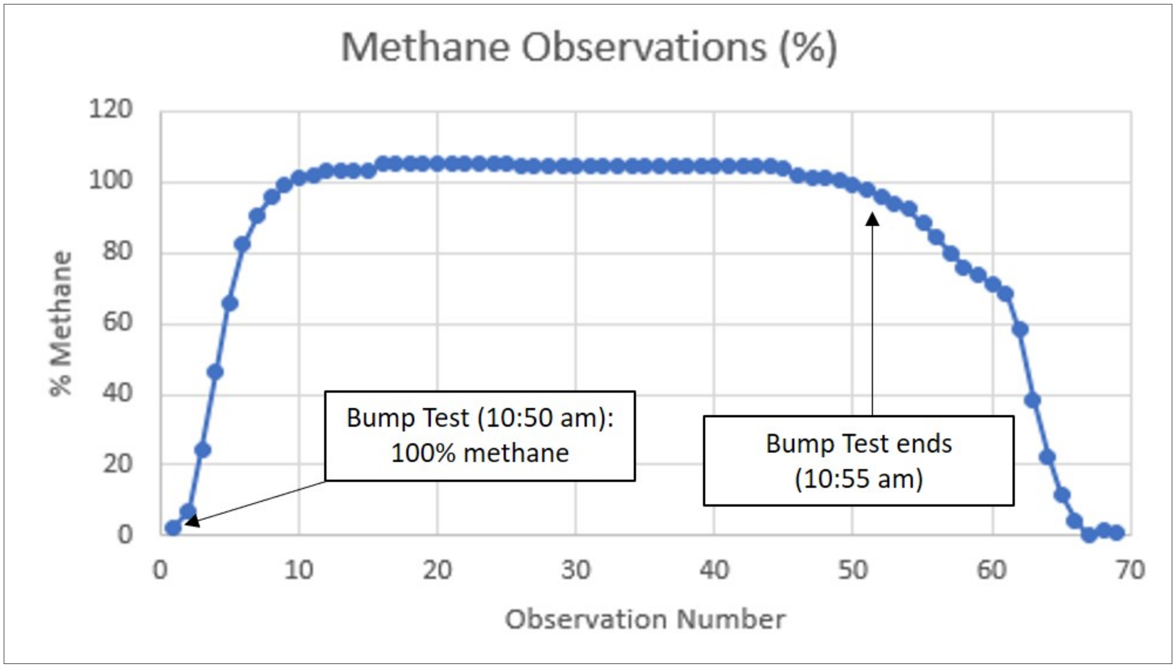

Figure 3-7. Methane Concentrations from the 100% Methane Bump Test

As presented in Figure 3-7, the results of the bump test indicate good responsiveness of the total methane sensor, in terms of peak identifications related to exposure of the high-level methane bump test. In terms of magnitude, the peaks were detected shortly after the known concentrations were injected.

In summary, the methane sensor showed good responsiveness to the bump test in terms of magnitude and duration.

3.3 Field Deployment

After testing of the sensor units, ERG shipped them to Utah for deployment. An ERG staff member residing in Utah met with the BRC staff to set-up the sensors at the Horsepool Monitoring Station (coordinates = 40.1437, -109.4672), as presented in Figure 3-8.

Figure 3-8. Horsepool Monitoring Station

Setup at the monitoring station was completed on February 4, 2020, as the sensor units were attached to tripods, hooked up to the monitoring site WiFi, and began taking measurements and streaming data.

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4.0 DATA REPORTING

This section describes the reporting of the measurements and compilation of the data into a master database.

Sampling at the Horsepool monitoring station began on 2/4/2020 and continued through 3/31/2020. The sensor deployment coincided with other field activities conducted by BRC staff related to this project.

4.1 Data Retrieval and Database Development

Minute-level measurements from the Lunar Outpost Canary-S sensor were transmitted wirelessly to Lunar Outpost's data portal. This data was retrieved daily via the subscription that ERG purchased. The downloaded raw file was merged into a master database, which was then QA'd and standardized into an analysis data table. In total, over 81,000 data records from the Canary-S sensor were obtained.

Five second measurements from the Dynament sensor were stored within the Raspberry Pi unit and daily files were e-mailed to ERG staff. The daily raw files were merged into a master database, which was then QA'd and standardized into an analysis data table. In total, over 764,000 data records from the Dynament sensor were obtained.

The analysis database consists of ten data fields, and these are presented in Table 4-1. Primary keys are denoted by the "*". The use of primary keys ensures no duplication of data and mitigates record growth. Appendix A-1 presents the measurements in Microsoft Excel.

Table 4-1. Data Fields in the Analysis Database

Field Name	Field Description
SENSOR_NAME*	Name of the Sensor
SAMPLE_DATE*	Date for when the measurement begins
START_TIME*	Start time for when the measurement begins
SAMPLE_DURATION	Duration of the measurement value
PARAMETER*	Description of the measurement parameter
VALUE_REPORTED	Concentration of the sensor measurement
UNIT	Unit of measure for the parameter
VALUE_ADJUSTED	Concentration value, adjusted after negatives were removed
NULL_FLAG	Flag to identify invalidated data records
ND_FLAG	Flag to identify a non-detect

The closest National Weather Service (NWS) Automated Surface Observing System (ASOS) station is in Vernal, Utah, which is 21 miles north of the Horsepool monitoring station. Hourly wind observations from this site, VEL (40.44092, -109.50992), was obtained for the study period. The data fields for the hourly measurements are presented in Table 4-2.

Table 4-2. Data Fields in the Analysis Database

Field Name	Field Description
METEOROLOGICAL_STATION*	Name of the meteorological station
STATION_ID	Station ID
OBSERVATION_DATE*	Date of observation
OBSERVATION_HOUR*	Hour of observation
WIND_SPEED	Wind speed in miles per hour
WIND_DIRECTION	Wind direction in degrees from north
NULL_FLAG	Flag to identify null values

Appendix A-2 presents the hourly observations in Microsoft Excel.

4.2 Data Distribution Statistics

Table 4-3 presents a comparison of the methane and total VOC concentrations from each sensor unit at the Horsepool monitoring station. The percent completeness ranged from 81.40% for the Lunar Outpost methane sensor to 100% for the Lunar Outpost total VOC sensor. Of note is that the methane concentrations amongst the two sensors was not close, in terms of average and percentiles.

Table 4-3. Summary of Concentrations for the Lunar Outpost and Dynament Sensors[a]

Pollutants	Sensor	Units	# Concentrations	% Detections	Arithmetic Mean[a]	Percentile Value[c]						
						5th	10th	25th	50th	75th	90th	95th
Methane	Lunar Outpost	PPM	82,224	81.40%	298.05 ± 2.01	0	0	11.28	225.22	507.83	713.26	817.35
	Dynament		748,542	94.95%	625.38 ± 0.76	0	100	400	600	800	1,100	1,300
Propane	Dynament	PPM	739,468	99.15%	461.51 ± 0.57	0	200	300	400	600	900	1,000
Total VOCs	Lunar Outpost	PPM	82,224	100.00%	0.260 ± 0.01	0.105	0.120	0.153	0.216	0.376	0.454	0.471

[a] In calculations involving non-detects (ND), ERG used a value of zero.

Figure 4-1 presents field results of the Dynament sensor for methane and propane. Over 739,000 measurements for each pollutant were generated.

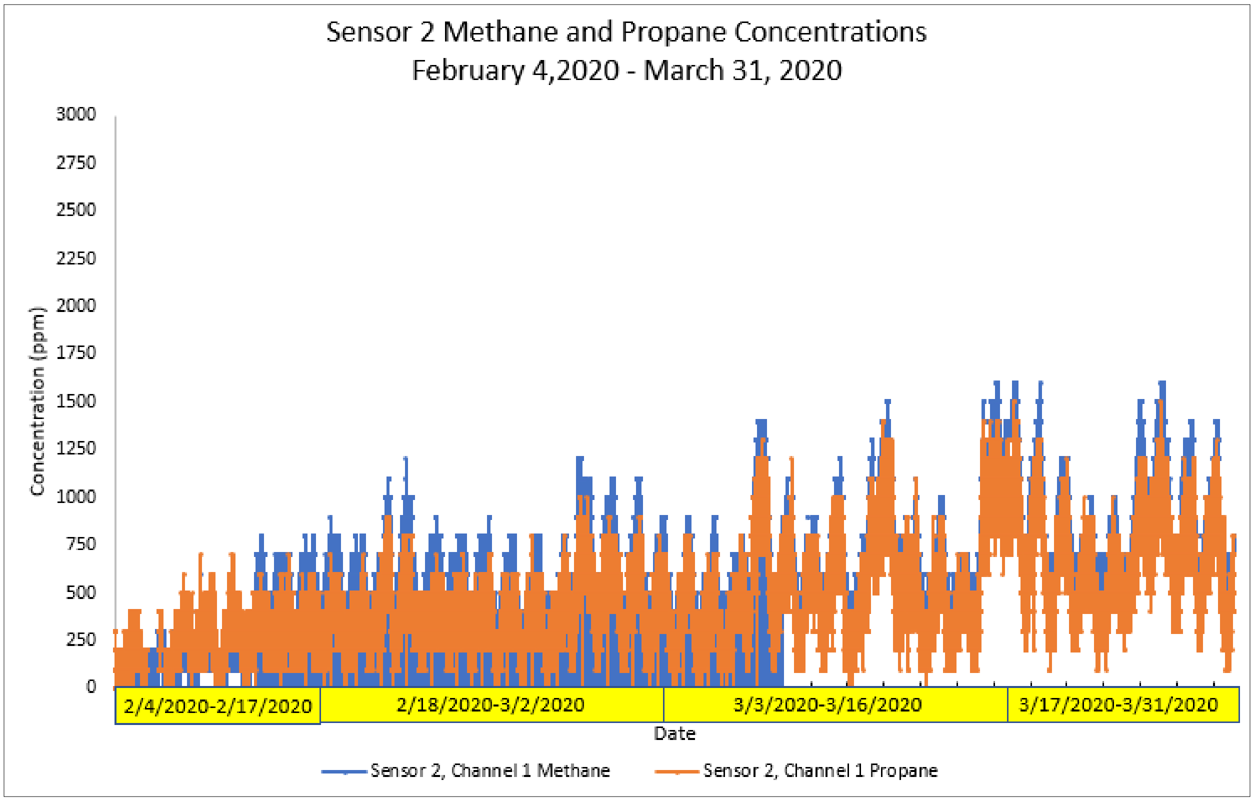

Figure 4-1. Field Results of the Dyanment Sensor at Horsepool from 2/4/2020-3/31/2020

The propane and methane concentrations trended very well together.

Figure 4-2 presents field results of the Lunar Outpost sensor for methane and total VOCs. Over 82,000 measurements for each pollutant were generated. Note that for ease of viewing, the total VOC data are plotted on a much lower scale.

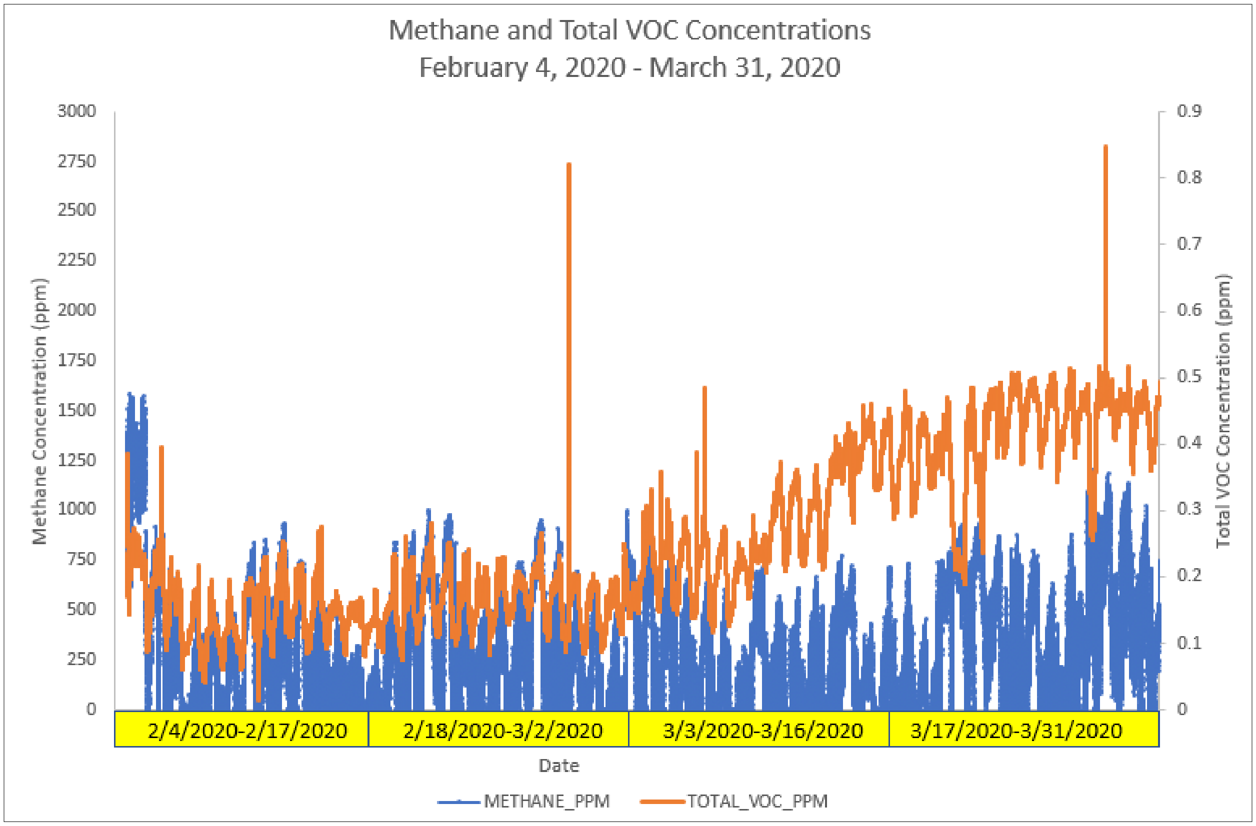

Figure 4-2. Field Results of the Lunar Outpost Sensor at Horsepool from 2/4/2020-3/31/2020

The methane and propane concentrations tended to track well together.

4.3 Source Influence Evaluation

The sub-hourly measurements were averaged to hourly averages and then paired with hourly wind observations from the VEL NWS station. The area around the Horsepool monitoring station is surrounded by oil and natural gas wells, as presented in Figure 4-3.[7]

[7] Well-level location and production statistics are available at: https://oilgas.ogm.utah.gov/oilgasweb/data-center/dc-main.xhtml#download.

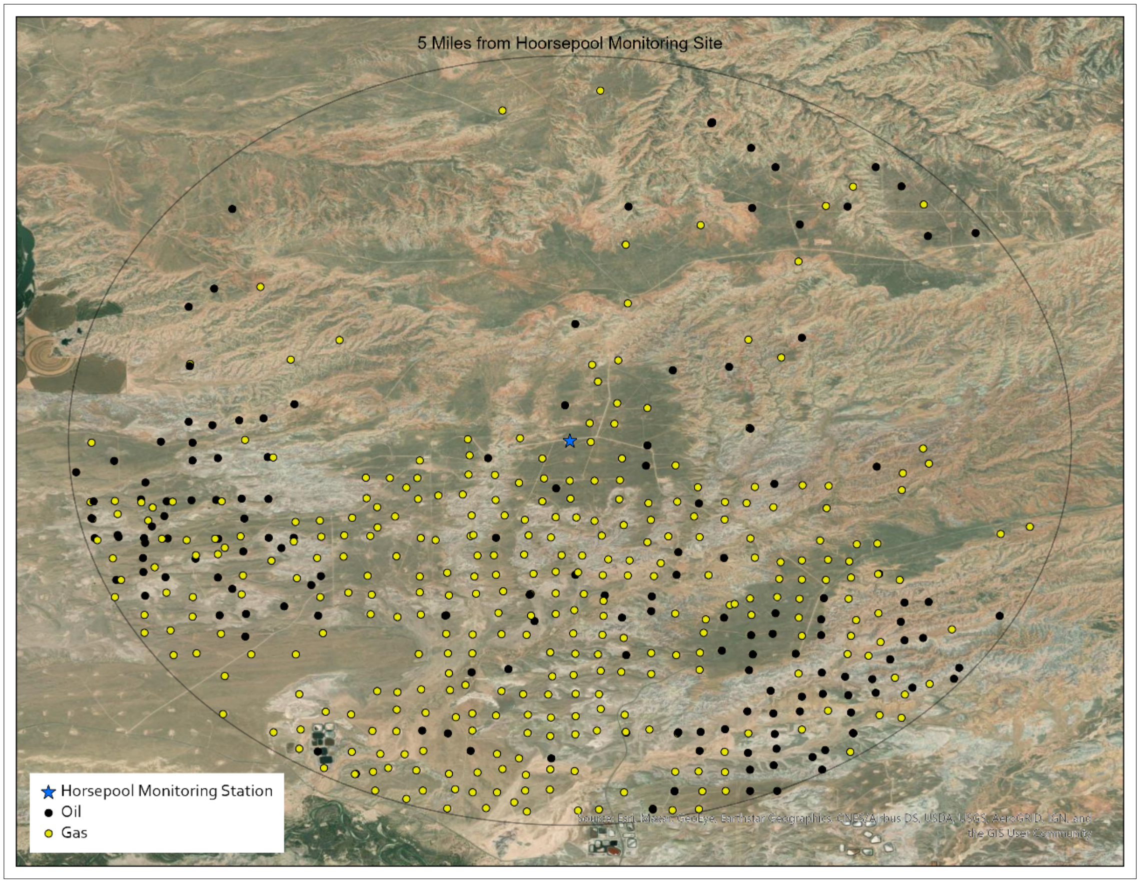

Figure 4-3. Location of the Horsepool Monitoring Station and Nearby Oil and Gas Wells

Pollution roses, which are concentrations plotted against the wind direction, are presented in Figures 4-4 through 4-6. Figure 4-4 is the methane pollution rose for the Dynament sensor, while Figure 4-5 is the methane pollution rose for the Lunar Outpost sensor. Both pollution roses show clusters to the west and east of the monitoring station, which reflects dense locations of oil and gas wells.

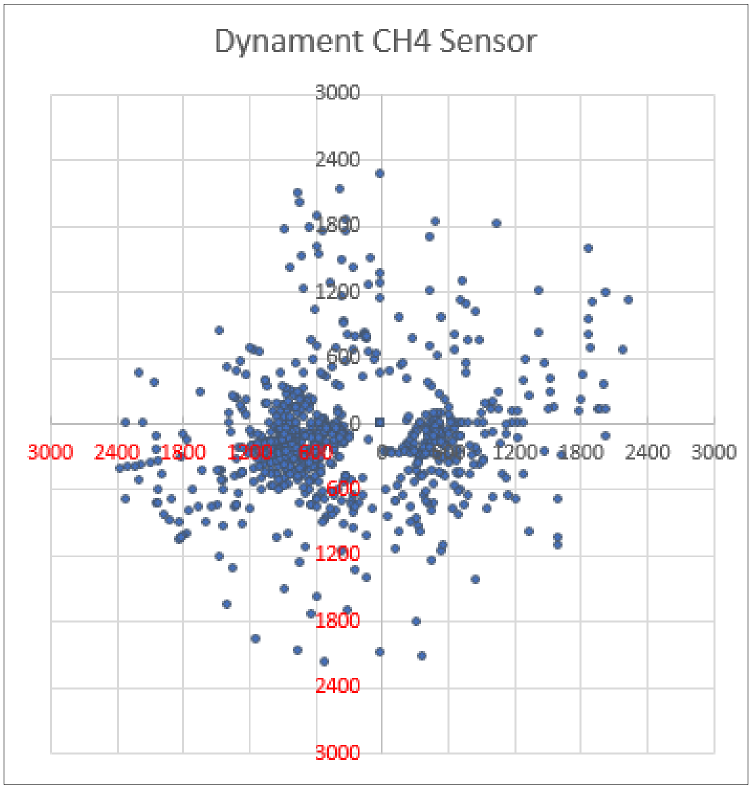

Figure 4-4. Dynament Methane Pollution Rose

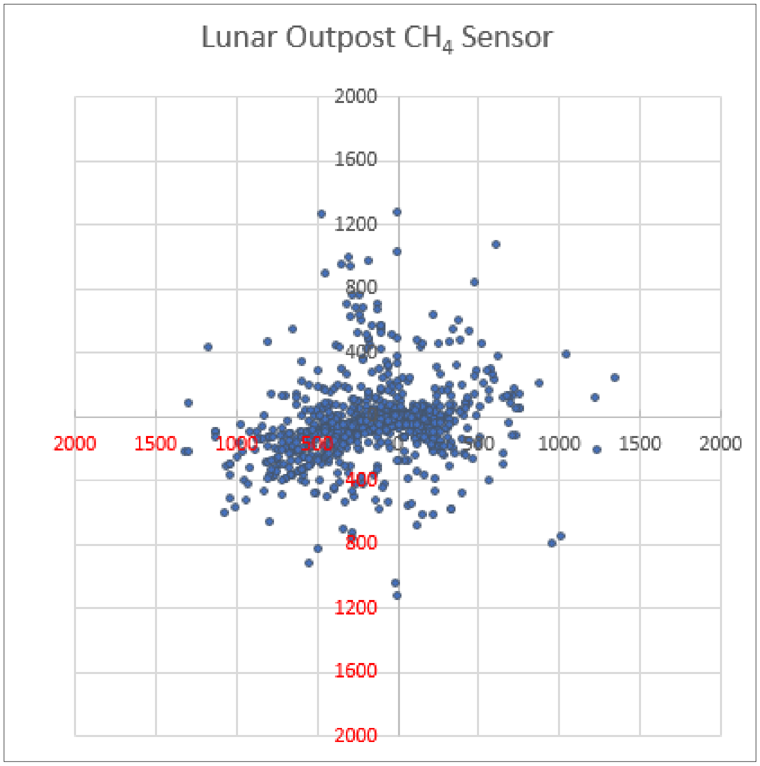

Figure 4-5. Lunar Outpost Methane Pollution Rose

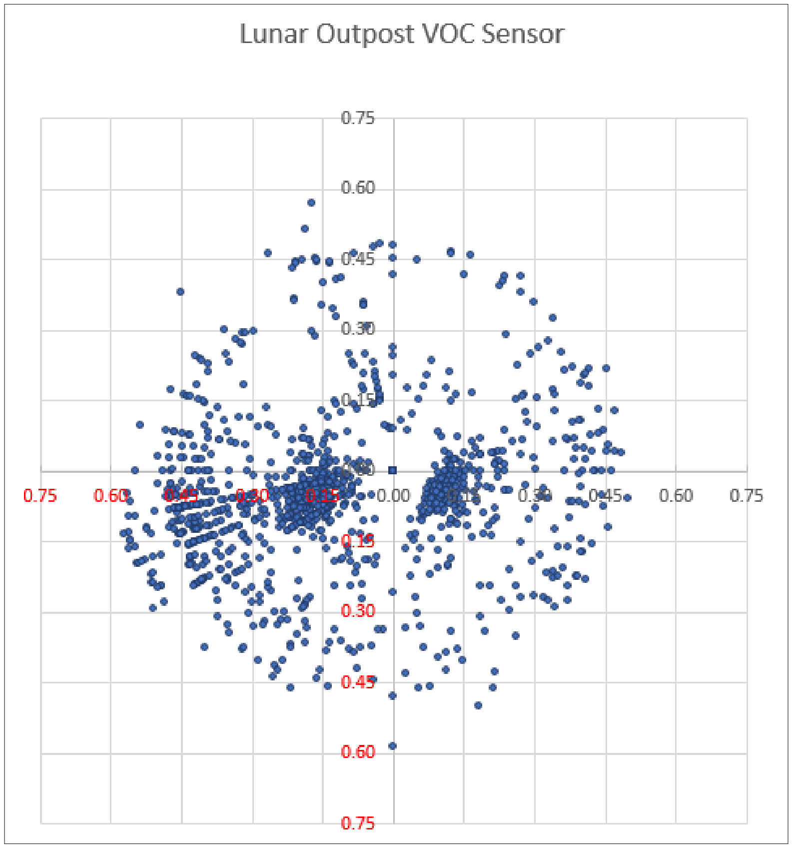

Figure 4-6. Lunar Outpost Total VOC Pollution Rose

The VOC pollution rose pattern is similar to the methane pollution roses, but larger concentrations are coming from the east to east-southeast.

5.0 OBSERVATIONS

This section summarizes the observations of this study.

During this study, several observations and lessons learned were gleaned. Each observation is placed under general groupings for organization.

5.1 Methane and Total VOC Sensors

- **Observation –** Methane and total VOC sensors were commercially available.
  - While over 60 sensors/sensor units were identified in this study, only 2 were selected for laboratory testing and field deployment.
  - Many of the identified sensors did not have published detection ranges applicable to ambient-level conditions.
  - By comparison, ozone, CO, and PM sensors are more readily-available and more easily commoditized from purchase to delivery.
- **Observation –** Information for commercially-available sensors was not always complete and/or accurate.
  - Information needed on the technical specification to assess the viability of sensors often required additional research and direct communication with the vendors.
  - The sensors ranged from build-it-your-own type sensor systems to turn-key systems.
  - Costing information for certain sensors was not consistent and was not complete as “add-ons” increased the advertised price.
  - Many of the commercially-available sensors often had lead times of 4-6 weeks from purchase to delivery.

5.2 Laboratory Testing of Sensors

- **Observation –** The Lunar Outpost and Dynament sensors performed well during laboratory testing.
  - For both sensors, ERG tested against known concentrations, and both sensors responded well in terms of responsiveness, magnitude, and duration.
  - The Lunar Outpost sensor was tested against an emissions sources, and responded well in terms of responsiveness, magnitude, and duration.

5.3 Concentration Data

- **Observation –** The performances of the Lunar Outpost and Dynament sensors were of mixed results.
  - Surprisingly, the percent detection rate for the Lunar Outpost methane sensor was less than 82%. Other detection rates were greater than 94%.
  - While the methane concentrations for both sensors were not similar in magnitude, they did exhibit similarities in identifying peaks.

- Our field tests showed that while these sensors are generally good for detecting CH_4 concentrations at source, they are not suitable to capture the lower ambient level of CH_4 concentrations in Uinta Basin.

- **<u>Observation</u> –** Integration of concentration data and wind direction confirm the presence of oil and gas wells surrounding the Horsepool monitoring station.
  - The ubiquitous locations of oil and gas wells are reflected in the pollution roses.
  - Higher methane and total VOC concentrations were higher in more dense areas of oil and gas wells to the east and east-southeast of the Horsepool monitoring station.

6.0 LITERATURE SEARCH RESULTS

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Appendix A. Sensor and Meteorological Data

(see “APPENDIX_A_SENSOR_DATA”)

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